ENVIRONMENTAL IMPLICATIONS OF DEEP-WELL DISPOSAL OF BRINES TO THE DETROIT RIVER GROUP OF FORMATIONS IN SOUTHWESTERN ONTARIO

SUMMARY REPORT

Prepared for

Ministry of the Environment
Southwestern Region
Province of Ontario

Prepared by

Underground Resource Management, Inc.
Austin, Texas

In Association With

Gartner Lee Associates, Limited
Markham, Ontario

1984

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NOTE:

THIS SUMMARY REPORT CONTAINS ONLY SELECTED SECTIONS OF THE FULL STUDY OF THE SAME TITLE. THE COMPLETE VOLUME IS AVAILABLE FOR REVIEW AT THE FOLLOWING LOCATIONS.

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INTRODUCTION

This review of the practice of waste injection into Devonian-age geological formations in Southwestern Ontario was conducted at the request of the Ministry of the Environment. Part of the Ministry's statutory function is to develop adequate controls to guide the siting, construction, and operation of disposal wells so that natural resources such as soil and water are protected. Industries that have used disposal wells in southwestern Ontario include the oil and gas production industry, the chemical manufacturing industry, and operators of underground storage caverns. Due to the relatively shallow depth of the disposal strata, and the occurrence of several events where the rock media failed to contain the wastes when high wellhead pressures were applied, there was a need to review the current status of the problem and to summarize and evaluate the risks associated with continued use of this disposal zone. The subject disposal intervals are part of the Devonian Detroit River Group. Underground Resource Management, Inc. (URM), in association with Gartner Lee Associates, Limited (GLA) was retained to provide this review document.

Subsurface injection in Ontario is regulated by both the Ministry of the Environment (MOE) and the Ministry of Natural Resources (MNR). MOE is primarily responsible for wells that dispose of industrial waste and the brine created when caverns are made by dissolution of bedded salt. MNR is primarily responsible for wells that inject oil field brines and fluids used for secondary recovery of hydrocarbons. Over the years, regulatory guidelines adopted by these agencies and their predecessors have evolved as problems have occurred and as new knowledge about the properties of the geologic system has been acquired. Regulations have been instituted by MOE to control the type of fluid, location, construction methods, and operating pressures of disposal wells

completed into the Detroit River Group. Use of this stratigraphic interval is now limited to the disposal of brines, although industrial process wastes would be permitted by MOE to be injected into deeper formations. Operating wellhead pressures of MOE-regulated wells are now limited to atmospheric pressure, or zero gauge pressure, which is also termed gravity drive. Static or shut-in water levels are required by MOE to be measured monthly and must be 10 feet (3 m) below the lowest occurrence of fresh water. No disposal into the Detroit River Group is permitted within five miles (8,050 km) of the St. Clair River. The government has encouraged investigations to identify deeper injection horizons where it is possible that higher pressures could be safely applied. This review document includes an assessment of the adequacy of present rules based on a review of the available geologic and hydrologic data.

The information that exists today includes data accumulated through regulatory reporting requirements, published literature on the geology, natural resources, and injection wells in southwestern Ontario, and the personal experience of many individuals both in government and in industry. Some existing information, primarily written records and personal experience of private industry, is not readily available. We have noted deficiencies in our knowledge throughout this report. In the course of this study, we have relied heavily for historical perspective on previous reports and memoranda written by personnel of MOE and MNR, and their predecessor agencies. Visits were made by URM staff to oil wells, disposal facilities, and an outcrop of the Detroit River Group. Previously unpublished well-test data were obtained and analyzed. This document is intended to be a guide to the available data, a summary of historical events, and a review of present knowledge. The behavior of underground fluids in the vicinity of wells has been reviewed in the context of the Devonian carbonate formations in southwestern Ontario.

Principles derived from the growing number of studies of other regional flow systems have been reviewed in the context of the geology and geography of the Great Lakes Region, and potential discharge areas have been listed.

This report is not an exhaustive, detailed study of all of the factors involved in this multifaceted problem. Further research may be required to answer specific questions and to determine appropriate MOE response to some of the presently perceived regulatory needs and obligations. As noted in the Conclusions, continued use of this disposal interval may require detailed consideration of individual sites. This review provides a summary of past and present operational details and regulatory efforts. The description of physical phenomena should help provide guidelines for answering questions about the adequacy of present regulatory requirements. We have made suggestions for possible amendments to present rules and procedures.

ACKNOWLEDGEMENTS

This study was made possible through the efforts of numerous individuals. The Project Group at URM was primarily responsible for the conduct of the study and the preparation of this report. The group was headed by Mr. Bob Kent of URM, and much of the analysis and writing was accomplished by URM hydrogeologist M. E. Bentley, with the assistance of hydrogeologist M. R. Schipper. Valuable support and assistance was provided by GLA scientists P. K. Lee and D. D. Slaine. Major contributions of information contained in the files of Ontario Ministry of the Environment were furnished by F. N. Durham, D. R. Brown, and J. M. Dochstader. Similar information from the files of the Ministry of Natural Resources was provided by R. M. Rybansky. An international perspective on the problem was provided by R. E. Ives of the Michigan Department of Natural Resources. Valuable assistance in editing this report was provided by MOE scientists D. Brown, B. Novakovic, T. Yakutchik, and G. Hughes. In addition, a number of individuals in private industry kindly shared their knowledge with project personnel.

CHAPTER SIX - REGULATION OF SUBSURFACE DISPOSAL

6.1 Purpose

Government regulation of waste disposal is designed to prevent trespass of potentially harmful materials belonging to one individual or organization onto the property or resources of another. In the case of subsurface waste disposal, the general invisibility of potentially damaging processes requires that extraordinary care be used to ensure that proposed operations have a sound technical basis. Although alternate means of disposal exist for the wastes that are potentially injectable, placement of the wastes underground can have economic and environmental benefits if the risks associated with this method can be reduced to levels equal to or less than those of the alternatives.

During the last twenty years, the government agencies responsible for managing the risks associated with waste disposal in Ontario have developed regulations to accomplish the protective functions required by statute. These rules specify basic procedures and performance standards, and so are general enough to cover different physical situations. The agencies that presently share authority for regulation of subsurface disposal are the Ministry of the Environment (MOE) and the Ministry of Natural Resources (MNR). The responsibilities of these agencies are described in the next section. The rules of the two agencies are not wholly consistent and correction of this situation should be considered. It has been concluded in this report that, under proper operating conditions, brine can be safely injected into the Detroit River Group. It is apparent, however, that present operating rules may involve some small risk that brine could flow upward into freshwater aquifers in some areas. The purpose of this chaper is to describe the regulatory framework in Ontario, to attempt to put the risks in perspective, and to suggest for consideration of MOE additional rules or modifications of

procedures that could help achieve the goals of MOE.

6.2 Regulatory Authority

Subsurface disposal of wastes in southwestern Ontario is regulated jointly by MOE and MNR. These agencies generally have assumed the responsibilities of their predecessor agencies, the Ontario Water Resources Commission, and the Ontario Department of Mines and Northern Affairs, respectively.

The MNR draws its authority from Bill 117, 4th Session, 28th Legislature, Ontario 20 Elizabeth II, 1971 entitled "An Act to Regulate the Exploration and Drilling for, and the Production and Storage of Oil and Gas". Also cited as "The Petroleum Resources Act, 1971". The MNR's primary responsibility and goal is to prevent waste of resources. To this end, the MNR has developed rules and regulations concerning the drilling, completion, location, and plugging of all types of wells except water supply wells. These rules are presently set out in Reg. 752 of Revised Regulations of Ontario, 1980 made under the Petroleum Resources Act. Section 37.1 of Reg. 752 states: "No person shall dispose of mineral water in an underground formation without the approval of the Minister." Mineral water is not defined in either the act or the regulation but is apparently interpreted to include industrial waste.

The MOE draws its authority from the Environmental Protection Act, Revised Statutes of Ontario, 1980, Chapter 141 as amended by R.S.O., 1981, Chapter 49, and the Ontario Water Resources Act, R.S.O. 1980 Chapter 361, amended in 1981. The MOE's primary goal and purpose is to provide for the protection and conservation of the natural environment. This is accomplished in part by regulating the activities of man as they relate to waste disposal.

6.3 Present Areas of Responsibility

No formal agreement exists between the MOE and MNR, however, some working relationships have developed. Available data suggest that the limited number of disposal wells in the region has limited the interaction between the two agencies. However, it is possible that an increasing number of applications for injection well permits will be received, and it many become desirable to formalize the working relationship between the ministries. The diagram shown in Figure 19 shows the general participation of each agency in the permitting process for the several different types of injection well permits. The types of wells that are covered by dual regulations are:

1. Industrial waste disposal wells,
2. Disposal wells for brines produced with oil and gas,
3. Disposal wells for brines resulting from creation of storage caverns in salt, ("ballast" brines used for displacement of product from caverns is considered to be industrial waste),
4. Wells used for pressure maintenance of petroleum reservoirs. (Secondary recovery wells). No "waste" disposal is involved.

The following types of wells are regulated exclusively by MNR: Oil and gas wells, solution-mining wells, and storage cavern wells.

Water wells are regulated exclusively by MOE.

In the case of industrial waste disposal wells (Figure 19), the MNR is generally responsible for permitting the well to be drilled, while MOE is responsible for reviewing geologic data, engineering plans for surface facilities and operational controls before issuing a Certificate of Approval to use the well as a disposal facility. Note that disposal of industrial wastes to the Detroit River Group is prohibited. The

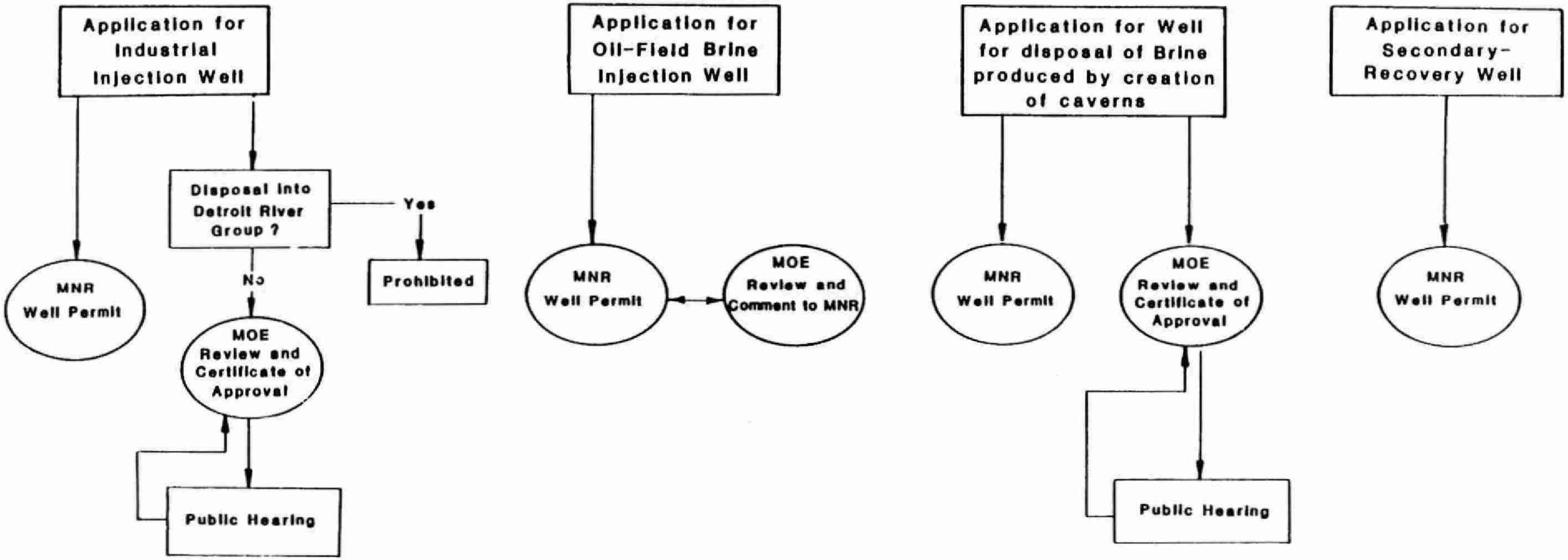

Figure 19. Diagram Showing Areas of Responsibilty of MOE and MNR in Permit Approval Process. Four Types of Wells are Shown.

Minister of the Environment may request a public hearing, which may be held by the Environmental Assessment Board. The procedure for wells that dispose of brine produced by the creation of storage caverns in salt is the same as for industrial waste wells, but there is no prohibitation against the use of the Detroit River Group. In the case of wells used to dispose of oilfield brines or secondary recovery wells, the function of the MOE is limited to a review of the permit application. MOE objections to any aspect of the application are transmitted to MNR. Each agency applies the regulations it has developed to meet its statutory obligations, approves applications that conform to the regulations, and advises applicants of the conditions and obligations that accompany the permit. Both agencies make available to applicants public data on oil, gas, and water wells to assist them in preparing applications.

In general, pressure limits are not specified in the regulations (O. Reg. 752 (MNR) or O. Reg. 152 (MOE)) which instead adopt the more flexible approach of investing in the Ministers the authority to set pressure limits as necessary. At present, wells that dispose of fluids to the Detroit River Group are required by the MOE to maintain a zero gauge flowing pressure (atmospheric pressure) at the wellhead (gravity drive only). The operators of these wells are required by MOE to record each month a 24-hour static water level at least 10 feet (3 m) below the base of fresh water. The MNR has now adopted the gravity-drive only rule for new oilfield brine disposal wells. The MNR does not ordinarily require the monthly shut-in test, but occasionally requests that this test be performed. The fluid-level standards of MOE and MNR do not consider the density of the fluid in the well. As noted elsewhere in this report, the allowable maximum flowing wellhead pressure may be slightly too high to provide a high degree of safety in high-risk areas. The risks have been described in the previous chapter and are reviewed below.

6.4 Present Rules

The present concept of permit applications places the responsibility to demonstrate the safety of a project on the applicant. The applicant must supply a broad range of information to MOE including data on the operating plan, site geology and ground-water hydrology, locations and plugging or completion reports of neighboring oil and gas wells within a 1-1/2 mile (2.4 km) radius that penetrate the disposal horizon, chemical analyses of the native formation water and the wastewater, names of adjacent mineral owners, a reservoir engineering report, a description of the proposed monitoring program, an outline of the testing and logging programs, and engineer's descriptions of the hole, the well, and surface facilities.

After review, the MOE may stipulate the following:

1. Maximum injection pressure or fluid level,
2. Maximum volumes or flow rates to be injected,
3. Monitoring requirements and report interval,
4. Installation of observation well(s) into the fresh- water zone or the injection zone.
5. Certain tests to be run on the well from time to time to demonstrate well integrity.
6. A condition that the operation of any disposal well may be limited or terminated and the well plugged if this action is found to be in the public interest.

We propose that MOE consider adoption of modified procedures in reviewing the data that pertain to several of the above classes of rule-making. In order to accomplish the statutory objectives of conservation and at the same time avoid unnecessary restraint of enterprise, it would be desirable to establish such rules after due consideration of the geo-

graphical and hydraulic character of each unique project. Adoption of standardized rules in some of the above areas appears to result in inadequate protection in some cases and may cause undue restraint in others. We recommend that MOE consider making changes in the review process of items (1), (3), and (4) above. These changes are described below.

6.5 Proposed Modifications to Present Rules and Procedures

6.5.1 Operating Fluid Levels: It is proposed that MOE consider some modification of the methods it uses to determine the operating pressures for individual injection wells. The maximum allowable operating fluid level is presently set at the elevation of the land surface at the wellhead in the case of the two wells presently operating. As described in Chapter 5, allowing this operating level may, in some cases, involve some risk that injected or native brines could move upward in conduits through the confining beds and into underground sources of drinking water. (Insufficient data are available to determine if this is true at presently operating wells.) This rule does not consider the density of the fluid in the wellbore, with the result that the maximum allowable bottom-hole pressure corresponds to the pressure that could be generated by a column of salt-saturated brine with a specific gravity of approximately 1.2, or up to 20% more pressure than would exist at the base of a column of fresh to brackish water.

Since, in a worst-case situation, this operating level could generate fluid levels in the disposal zone 50 to 100 feet (15 to 30 m) above land surface, it is important to perform a more detailed analysis of local conditions to determine the likelihood that this could occur, and in what size area, in order to gauge the possible effects on local ground-water resources. We propose that the object of such an analysis be the determination of the size of the "critical area" where water

levels in piezometers or conduits would be above static water levels in the overlying ground-water aquifer. Operating pressures can then be stipulated which would limit this area to a size that presents acceptably small risks or is monitorable.

The size of the critical area should be determined by the methods outlined in Chapter 5. An important requirement is the quantification of the hydraulic properties of the disposal zone. The applicant would be responsible for conducting tests to determine these properties. This need not be done if the applicant is willing to accept a low operating fluid level, such as the base of fresh water or lower, that could be stipulated based on expectation of worst-case conditions. If the applicant desires the maximum prudent operating fluid level or pressure, he would accept the responsibility for gathering the data necessary for determination of that limit in a technically sound manner.

Well tests would have to be carefully conducted in order to define the response of the disposal zone to injection. The parameters to be determined include the storativity and flow capacity of the disposal zone. Determination of the storativity will require use of one or more observation wells during the test. The validity of measurements taken in such a well should be confirmed by assuring that the response of the observation well is representative of the reservoir using methods described in Chapter 5.

If the hydraulic parameters of the disposal reservoir are known, an initial set of curves of pressure versus distance from the injection well can be constructed for various flow rates by assuming the aquifer is of infinite areal extent. Next, curves can be constructed to depict equivalent water levels for different fluid densities likely to occur in possible conduits through the confining beds. Additional sets of curves

can be constructed for different durations of injection, as required. By comparing such curves with profiles of reported freshwater heads, the size of the "critical area" can be determined for all the different conditions of flow rate, time, and density that may occur during the "infinite-acting" period, before the effects of flow boundaries appear.

The next step would be a review of other data on ground-water resources within some appropriate distance of the injection well. This distance can be derived from the water level vs. distance curves for the injection zone. Among the characteristics of water usage relevent to this problem are the head of fresh water, the locations, number, flow rates, and usage cycles of water wells, and the radius of influence of water wells as calculated from aquifer parameters that were measured or were estimated from specific capacity data or other information. This information can be used to determine the extent of the area around a pumping water well where the pumping level in the aquifer could be below the estimated levels of fluids in possible conduits while the injection well is in operation. The risk that a conduit may exist within this area is proportional to the size of the area.

As the flow rate of an injection well is increased, the size of the critical area around the well would increase. The risk that a conduit exists in this area increases as the size of the area increases. In the example that was presented in Figure 17, the size of the critical area is very small. If the static water level in the freshwater aquifer were 40 ft. (12 m) above the base of the aquifer, then the cricital radius would be only 20 feet (6 m). Such a small critical area would not, in our opinion, constitute a significant endangerment of water resources.

If the injected fluid has a higher density than the native brine,

the water levels that could occur in conduits in the area where the heavy fluid exists near the well would be reduced. This calculation could be made periodically during the life of the project, at which time the allowable pressure or fluid level could be reviewed by MOE.

If the critical area around the injection well is large enough to cause concern, the area may still be "managed" if it is small enough to feasibly monitor water quality with observation wells completed in the freshwater aquifer. The operator of the disposal well could design the plan of an array of monitor wells based on aquifer properties that were obtained for the calculation of the area of influence around local water wells. If the water supplies were judged too vital to allow temporary or permanent replacement from another source, then allowing a "managed" critical area could be ruled out. If a managed area is allowed, the observation wells would be sampled periodically to detect changes in water quality within the critical area. The amount of change of dissolved solids in the samples which would signal cause for alarm should be established at the start of the project by compiling data on natural waters in the region surrounding the injection well. This data should give an indication of the maximum salinity of naturally-occurring waters in the aquifer. Increases in total dissolved solids content (TDS) of water samples from the monitor wells should be viewed with alarm if TDS increases from an initial "normal" baseline level to a level that exceeds the established local maximum by a factor of 2 or 3. If no satisfactory explanation for the increase can be proposed, the rules governing the injection operation could be modified, or the operation could be terminated, and normal MOE policy with regard to remedial action would apply.

The area beyond the critical area around the disposal well would not be subject to high risk of contamination. Contamination can occur

only while a water well is pumping. A conduit must exist very close to a water well in order to be within the area where the cone of depression is deep. If the source of upward migrating saline water were very close to a water well, conditions will be favorable for early detection so that remedial action may be taken. In addition to a course of action to reduce the allowable operating level in the injection well, another option would be to have the operator replace the water supply, perhaps with a new well in a different location, since discontinuing use of the well should eliminate the intermittent head differential caused by pumping the well, which should stop the entry of saline water into the aquifer. The probability of the existence of faulting and fractures in the critical area should be evaluated. Structure maps of the disposal zone or of a shallower horizon should be constructed.

In the above discussion, it has been assumed that the pressure vs. distance pattern in the disposal reservoir could be predicted with some confidence from the hydraulic parameters of the reservoir. This should be true during the "infinite-acting" period before the effects of flow boundaries appear. After this occurs, the shape of the pressure profile will become more difficult to predict by mathematical means. It would be desirable to actually measure the changes in reservoir pressure that are occurring through time so that the operator can demonstrate that the disposal project continues to meet the performance standards set by MOE. The observation wells that were installed to conduct initial well tests to define the reservoir characteristics can serve this purpose as well. Fluid levels in observation wells completed in the disposal reservoir should be measured continuously, and the full record should be submitted periodically to MOE. The observation wells will also enable adequate monitoring of the effects of multiple wells completed in the same disposal reservoir.

It is apparent from the preceding discussion that it will be necessary to decide on the level of risk which cannot be tolerated. These questions include (1) what is the allowable size of a critical area? (2) Should a "managed" area be allowed? (3) What size of radius of influence of water wells constitutes an unacceptable risk that a conduit could be present very close to the well? The answers to these questions should be formulated after consideration of all possible information on the disposal reservoir and freshwater resources in the vicinity of each disposal project. The Ministry has, by statute, wide latitude to decide on appropriate operating levels. This flexibility is similar to that given other regulatory agencies in other regions.

As an example of a low-risk situation, the disposal reservoir may be shown to offer a substantial resistance to flow such that the "cone of impression" caused by injection is small and very steep near the disposal well. If this can be verified with some confidence by tests employing observation wells, an operating level could even be allowed above the land surface if, for example, the critical area extended only a short distance from the injection well, and monitor wells were installed in the freshwater aquifer. In our opinion, there is no need to bar the use of injection pumps if the hydraulics of injection are well known, and the risks are very low due to rapid attenuation of injection pressures. On the other hand, the disposal zone may be so nonhomogeneous that communication cannot be established between the disposal well and observation wells. It is possible that very high rates of injection can be accomplished with only moderate pressure increase in the disposal well. If this pressure increase does not register at the observation wells, then the size and shape of the critical area would be unknown. Such a situation would probably call for either the establishment of a low allowable operating level or pressure, or the drilling of additional observation wells until the

reservoir can be adequately defined. The applicant could decide whether it is worth an additional investment in observation wells in order to determine whether a higher allowable operating flow rate could be obtained.

It is more important to specify an allowable operating bottom-hole pressure than to specify an allowable operating fluid level. The process of review and rulemaking involves calculations based on pressure versus distance from the injection well, since these may be made without regard for the density of the injected fluid. Density becomes important when possible fluid levels in conduits are considered. We recommend that MOE consider specifying only maximum bottom-hole pressure in the injection well. The applicant could then be given the choice of measuring and reporting this pressure, or converting this pressure limit to a fluid level, using the density of salt-saturated brine (specific gravity approximately 1.2), and measuring and reporting fluid levels. It would be to the operator's advantage to monitor bottom-hole pressures to avoid sacrificing some of the allowable driving force when low-density fluids are being injected. Since measurement of bottom-hole pressure would involve placement of a measurement instrument in the bottom of the well, a continuous record of injection pressures could be produced. Monthly fluid-level measurements should still be made to check the calibration of the measurement system.

Measurements of shut-in pressure should continue to be made in order to follow the progress of reservoir fillup, so that the conditions under which the reservoir are abandoned will not threaten freshwater resources. The stipulation of an "abandonment pressure" should be based on the same principles as those employed to determine safe operating pressures. We recommend that the reservoir pressure on abandonment be set low enough so that fluid levels in conduits would not be above the

static heads in the freshwater aquifer.

6.5.2 Monitoring: In order to follow the changes in pressure versus distance from the disposal wells that will occur during injection into complex, bounded reservoirs, pressures should be measured in one or more observation wells installed near the disposal well. The well should not be located far outside the critical area, or the true size of the critical area will not be known with certainty.

Water levels or pressures would have to be continuously monitored in observation wells in order to detect occurrences of maximum levels. If water levels are measured, a sample of water should be periodically taken from these wells in order to determine its density so water levels can be converted to bottom-hole pressures. Probing the fluid column periodically with a conductivity instrument would ensure that the fluid sample was representative of fluid at all levels in the well.

Initially, area water wells should be sampled in order to establish baseline water-quality conditions in the aquifer throughout a wide area selected by consulting the pressure vs. distance diagrams. The mile and one-half radius currently employed should be adequate for this. If it is decided to permit a "managed" critical area, then the monitor wells within this area should be sampled initially to define baseline conditions also. In the case of a very small critical area, a single well completed in the freshwater aquifer could be installed near the disposal well. After operations begin, the monitor wells in the critical area should be sampled on a regular basis. In general, the sampling interval should be more frequent for wells nearest the disposal well. Sampling intervals could also be based on calculated rates of flow in the freshwater zone. Aquifers with low permeability and low flow rates would not require sampling as often as aquifers where flow rates are higher.

Wells that make large withdrawals from the aquifer should receive special attention since they sample a relatively larger part of the aquifer.

6.6 Existing Injection Wells

A number of active and inactive waste disposal wells currently exist in southwestern Ontario. It is proposed that MOE consider reviewing the status of these wells in order to ensure that they present no hazard to fresh-water resources.

6.6.1 Abandoned Wells: The abandoned injection wells in southwestern Ontario include wells that were used to dispose of industrial wastes and those that were used to dispose of brines from caverns or oil fields. Some of the wells that were used to dispose of industrial wastes in and near Sarnia, Ontario, apparently have pressures at the land surface that are greater than atmospheric. The mechanical integrity of most of these wells has probably not been determined in over ten years. Abandoned wells represent potential pathways for brines or wastes to move from the disposal zone into sources of usable ground water. These wells should be plugged.

6.6.2. Active Wells: There is little data available on the properties of the injection zones into which presently operating disposal wells inject cavern-washing brine. Without such data, the risks associated with operation of these wells under present rules cannot be evaluated. The present shut-in water levels in the disposal wells are now near the base of fresh water, however, they apparently decline with time, indicating that if the reservoirs are bounded, they may have somewhat permeable boundaries.

MOE has installed a water level recorder in the "Prefontaine" well

located approximately one mile (1,609 m) from active well I.D. No. 13. The Prefontaine well is completed in the Detroit River Group. The fluctuations of the recorded water levels in this well suggest that the water levels are strongly influenced by injection in wells No. 13 or 15. Unfortunately, the current reservoir pressure at the Prefontaine well cannot be determined because the density of the fluid in the well is unknown. The fluid level in April, 1982 was approximately 105 feet (32m) below the land surface. Static water levels in fresh water in the vicinity of Well I.D. No. 13 are at a depth of approximately 30 feet (9.1m). If the fluid in the Prefontaine well is fresh water or low-density saline water, then the head in the disposal reservoir is substantially below the head of fresh water. If the fluid in the Prefontaine well is saturated brine, and the primary transmissive zone is at the top of the Detroit River group at a depth of 538 feet (163m) then the bottom-hole pressure would be (538-110) (.433) (1.2) = 222 psi (1,530 KPa). In terms of fresh water, this corresponds to a fluid level 24 feet (7.4m) below land surface, or approximately at the level of head of fresh water.

The Prefontaine well and the array of wells operated by the disposal company appear to represent a favorable situation for conducting multiwell tests of the Detroit River Group in an area where lost-circulation zones exist.

SUMMARY

As a result of our examination of published literature, public records, consultant's reports, and interviews with consultants and well operators, we have made the following conclusions about the environmental implications of injection of brine into the Detroit River Group in southwestern Ontario.

1. The study area lies on a flexure between two mature, compacted continental basins of Paleozoic Age, the Michigan Basin and the Appalachian Basin.

2. The Detroit River Group in southwestern Ontario is composed of finely crystalline to microcrystalline dolomite with thin beds of anhydrite. The Group is approximately 450 ft. (137.2m) thick in Lambton County. In some areas, the anhydrite has been dissolved, resulting in intervals of high porosity and permeability ("lost circulation zones"). The formation is overlain by shales and fine-grained limestones. The bedrock is overlain by clayey glacial till that contains erratically productive fresh-water bearing sand layers. The till is 100 to 150 ft. (30.5 to 45.7m) thick in the Sarnia area.

3. In the area between the structural basins, the formations have gentle dips in the direction of the basin centers. Major faults are not numerous, but a wide area has been affected by dissolution of Silurian salt beds, causing younger rocks to have anomalous areas of thickening, thinning, and irregular stratigraphic contact surfaces. The disturbances are visible on structural maps of the top of the bedrock, so the entire Devonian section has been affected. Dissolution was

contemporaneous with deposition. The effects of collapse and localized faulting on the permeability of the Detroit River Group or the overlying confining beds are not well documented.

4. There is a low level of seismic activity in southwestern Ontario. Microtremors have occurred in the vicinity of the Gobles oil field near Woodstock, Ontario. In this field, fluids are injected under moderate pressures for the purpose of secondary recovery of petroleum from a Cambrian-age reservoir. No seismic activity has been linked with injection into Devonian-age strata, however.

5. An interval near the top of the Lucas Formation of the Detroit River Group has been utilized for disposal of industrial waste, oil-field brine, and brine from creation of caverns in salt. The interval occurs at a depth of 500 to 800 ft. (154.4 to 243.8 m) in the industrialized area of Lambton County near Sarnia.

6. Results of seven injection tests and drill-stem tests of injection wells yield values of formation flow capacity ranging from 2,360 md-ft(0.53 m^2/day) to 117,000 md-ft(26.5 m^2/day). One value was too high to accurately calculate with data from the equipment employed. Late-time trends of pressure vs. time, recorded in the tests of some of the reservoirs, are similar to those ordinarily obtained in tests of homogeneous granular porous media. Several of the reservoirs tested were described by applicants as "lost-circulation zones".

7. The areal extent of individual "lost-circulation zones" or regions with other types of porosity is reportedly limited.

Some operations have experienced reservoir "fillup", a behavior that probably indicates that fluids have been injected into a bounded reservoir.

8. In the late 1950's, the 1960's, and the early 1970's, disposal wells, located primarily in the Sarnia area, utilized wellhead pressures up to 450 psi (3,100 kPa) to achieve injection rates of 50 to 100 gal/min(273 to 545 m^3/day).

9. Several incidents occurred where industrial wastes appeared at the land surface within several hundred feet of injection wells, and brines apparently emerged at greater distances. Flows occurred in the U.S. city of Port Huron, located across the St. Clair River from Sarnia. Most of the reported incidents occurred in the vicinity of Sarnia and near Courtright.

10. The wastes and brines apparently flowed to the surface through abandoned, improperly plugged boreholes that were drilled up to 90 years ago in search of gas in the Dundee Formation, which overlies the Detroit River Group. Many of these wells penetrated to the porous horizons in the Detroit River Group.

11. As a result of the breakout of brine and waste liquids, the government enacted legislation to phase out injection of industrial waste into the Detroit River Group in areas located within five miles (8 km) of the St. Clair River. Further injection of industrial wastes other than brines into this formation was prohibited, and wells governed by MOE were limited to injection at atmospheric pressure only (gravity flow).

12. Government concern over the desirability of contined use of the Detroit River Group as a disposal zone resulted in this review of the problem and of potential environmental consequences of continued use of the formation for the disposal of mineral brine.

13. Disposal wells are required to have the long casings cemented from the disposal zone to ground surface. Liquids are injected through tubing set on a packer. The annular space between tubing and casing is filled with pressurized, noncorrosive fluid, and the annulus pressure is continuously monitored to ensure that no leaks develop in the tubing or the casing.

14. Applications for disposal wells are required to contain the plugging or completion records of all exploratory borings or oil and gas wells within a 1-1/2 mile (2.4 km) radius of the well site, to ensure that there are no artifically created passages through the confining beds. Many oil well casings are cemented only through the producing interval and the annular space is open opposite the Detroit River Group. These wells are plugged by "squeezing" cement through perforations in the casing.

15. Disposal wells completed in the Detroit River Group presently are not allowed to utilize wellhead pressures greater than atmospheric pressure. Pumping of waste is not permitted, therefore injection is by "gravity drive". Once a month, a 24-hour static water level is measured in wells regulated by MOE. This level is required to be 10 ft. (3 m) below the base of fresh water.

16. The adequacy of the operating rules that have been adopted for injection wells completed in the Detroit River Group was examined by reviewing failure modes in the context of the regional hydrogeological environment, the history of oil exploration, well construction techniques, the location and abundance of resources, and the hydraulics of radial flow in porous media. The primary concern of this part of the evaluation was prevention of local, early escape of poor-quality water from the injection zone which could endanger underground sources of drinking water.

17. The presence of undetectable artificial openings in the confining beds in some parts of southwestern Ontario presents a hazard that requires restrictions on the operating pressures of injection wells.

18. To achieve relatively safe emplacement of wastes, fluid levels in possible openings in the confining beds during operation should be limited to a level lower than the static water levels in the fresh-water aquifer. The comparative risks of different operating levels can be estimated by determining the critical area within which levels will be above static fresh-water heads.

19. The radius of influence of the injection operation should be calculated using reservoir properties determined from multi-well tests. The pressure profiles can be converted to water levels based on the density of native formation brine. These water levels can be used to determine the sizes of "critical areas" where the levels would exceed fresh-water heads at different injection rates. Selection of an operating level

should be based on this information.

20. If a "critical area" is allowed, its size could be continuously confirmed by monitoring of observation wells completed in the Detroit River Group, in order to detect changes in pressure trends which can be caused by long-term injection into bounded reservoirs, or interference between multiple injection wells. Monitoring of the quality of fresh water within this area could be required. Monitor wells that penetrate the Detroit River group must be carefully constructed to ensure that a potential for upward leakage at such wells will not be created.

21. Good operating practice requires that pressures within a "critical area" in the disposal reservoir return to a safe level after injection has ceased. This level should be low enough to insure that no upward-directed head gradient could exist for an unpredictable amount of time after shut down. Monthly checks of shut-in pressure or fluid levels should serve to confirm the absence of critical pressure increases.

22. It is recommended that only those areas where the Detroit River Group contains water with more than 3,000 mg/L TDS and is overlain by more than 300 feet (91 m) of bedrock confining beds be considered for disposal of brine.

23. The long-range goal of safe subsurface disposal is to effectively confine the brine to the disposal zone for a very long period of time in order to assure maximum opportunity for dilution, alteration, and slow ultimate discharge. The regional flow system should ideally have a very low flow rate.

24. Potentiometric and chemical data are probably insufficient to make an exhaustive study of the regional hydrodynamics of the Detroit River Group, but the principles of gravity-driven flow suggest that the nearest likely discharge areas are topographically low areas occupied by Lakes Huron and Erie and the connecting waterways.

25. Water of good quality occurs in the subcrop zones of the Detroit River Group and may be present some distance downdip of the point where the waters become confined by the overlying Dundee Formation, but sufficient data have not been compiled with which to delineate this limit. Waters fresher than sea water (<35,000 mg/l TDS) occur in a wide region in downdip areas, and are found in much of eastern Lambton County. Brines occur in northwestern Lambton County.

26. Inferred head data suggest that there is a potential for regional flow from the most elevated subcrop near Stratford toward possible discharge areas occupied by Lakes Huron and Erie and the connecting waterways.

27. Head levels in the Detroit River Group in Lambton County do not appear to be high enough to cause discharge in this area. The rate of regional flow in the Detroit River Group in Lambton County appears to be very low. Injection of fluids under present and proposed conditions will have a negligible effect on regional discharge.

28. Isolated occurrences of anomalously saline water in the glacial aquifers in Lambton County may represent areas where molecular diffusion is effective in transport of solutes upward

through the bedrock. Scattered occurrences of present or former natural openings in the confining beds are also suggested by the presence of oil in the glacial deposits at sites that are located directly above reservoirs in Devonian-age strata. Neither phenomenon requires an explanation based on advection by upward-moving water. Occurrence of abnormally saline ground water near an injection well should be monitored carefully, however.

29. Ministry regulations have been developed to accomplish the protective goals established by government statute. The rules have evolved in response to the increase in the general knowledge of the hydrogeology of the Detroit River Group. The Ministry may want to consider modifying present evaluation methods to allow consideration of reservoir hydraulics and aquifer usage near each individual project. Criteria have been outlined by which sites of high or low risk may be identified.

CONCLUSIONS

The available data suggest that continued injection of brines into the Detroit River Group can be accomplished relatively safely under extraordinary operating rules. The vast majority of ordinary disposal wells in North America operate under different principles. In most wells, shallow fresh-water resources are protected from the elevated fluid pressures in the reservoir near the well by intervening low-permeability confining beds. This technique cannot be relied upon in Southwestern Ontario due to the large number of undocumented abandoned boreholes.

Present operating rules specify a maximum operating fluid level at the land surface. It is proposed in this report that the review process employed by the Ministry of the Environment be modified in order to consider the differences in hydraulic character of the Detroit River Group in different areas. Also, the character and usage of fresh-water resources in the vicinity of the disposal well will affect the level of risk associated with the project. Individual consideration of each unique disposal project will avoid setting operating levels too high in areas of extremely unfavorable conditions, and conversely, setting levels too low in areas where conditions are favorable.

The proposed methodology would require more detailed information to be gathered by the applicant than was previously necessary. This would be unnecessary if the applicant agrees to operate at a very low pressure or fluid level that was based on expectation of worst-case conditions. If the applicant desires to operate at the maximum prudent level, he would accept the responsibility for determination of the properties of the disposal zone necessary to properly evaluate the area of endangering influence of his well. An analyst would calculate the radial decline of

several assumed bottom-hole injection pressures and then convert these pressures to fluid levels using the density of the native formation brines, which would be the fluids most likely to reside in or invade undocumented boreholes. The profiles of fluid levels would be compared to profiles of fresh-water heads to determine the size of the "critical area" or "area of endangering influence" that would occur at different operating bottom-hole pressures at different times, initially assuming a reservoir of infinite size. The Ministry could then choose a maximum operating bottom-hole pressure based on the area of endangering influence that appeared to present an acceptable level of risk. It is expected that due to the presence of undocumented boreholes in unknown locations, the area chosen should probably be restricted to a size which could be effectively monitored using wells installed in the fresh-water aquifer.

In this report, the "critical area" is based on the head of fresh water rather than the base of fresh water. Most of the wells in rural southwestern Ontario are employed only intermittently to produce water for domestic and stock usage. When the wells operate, the cone of depression of heads is relatively steep and narrow, with the result that the area in which drawdowns are deep is relatively small. The chance that an undocumented borehole occurs very close to a water well is small, and the required proximity for contamination would tend to promote rapid detection of the contamination.

Since the radius of influence of the injection well will grow unexpectedly if boundary effects begin or if multiple injection wells interfere with each other, any observation wells completed in the disposal reservoir could be continuously monitored so that the applicant can demonstrate at any time that his disposal project meets the performance standards set by MOE.

Operators of disposal wells could monitor either operating fluid levels or operating bottom-hole pressure, but it would be to their advantage to monitor the latter. Since the hydraulic analysis would be based on bottom-hole pressures, the pressure stipulated by MOE would have to be converted to a water level using worst-case fluid density (salt-saturated brine, specific gravity = 1.2) in order to prevent exceeding the allowable pressure when using water-level criteria when this type of brine was injected. The operator would not be able to inject at the maximum allowable bottom-hole pressure if low density fluid were injected at an operating level based on saturated brine.

In summary, it should be the responsibility of the applicant to demonstrate the safety of a disposal well. The applicant should make the decision whether the expenditures for monitoring facilities justify the potential returns from utilizing possible increased flow rates. The Ministry of the Environment should objectively base operating rules on technical principles applied to site-specific data. The resulting rules would ideally be neither unduly restrictive nor uncautiously liberal.

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A P P E N D I X

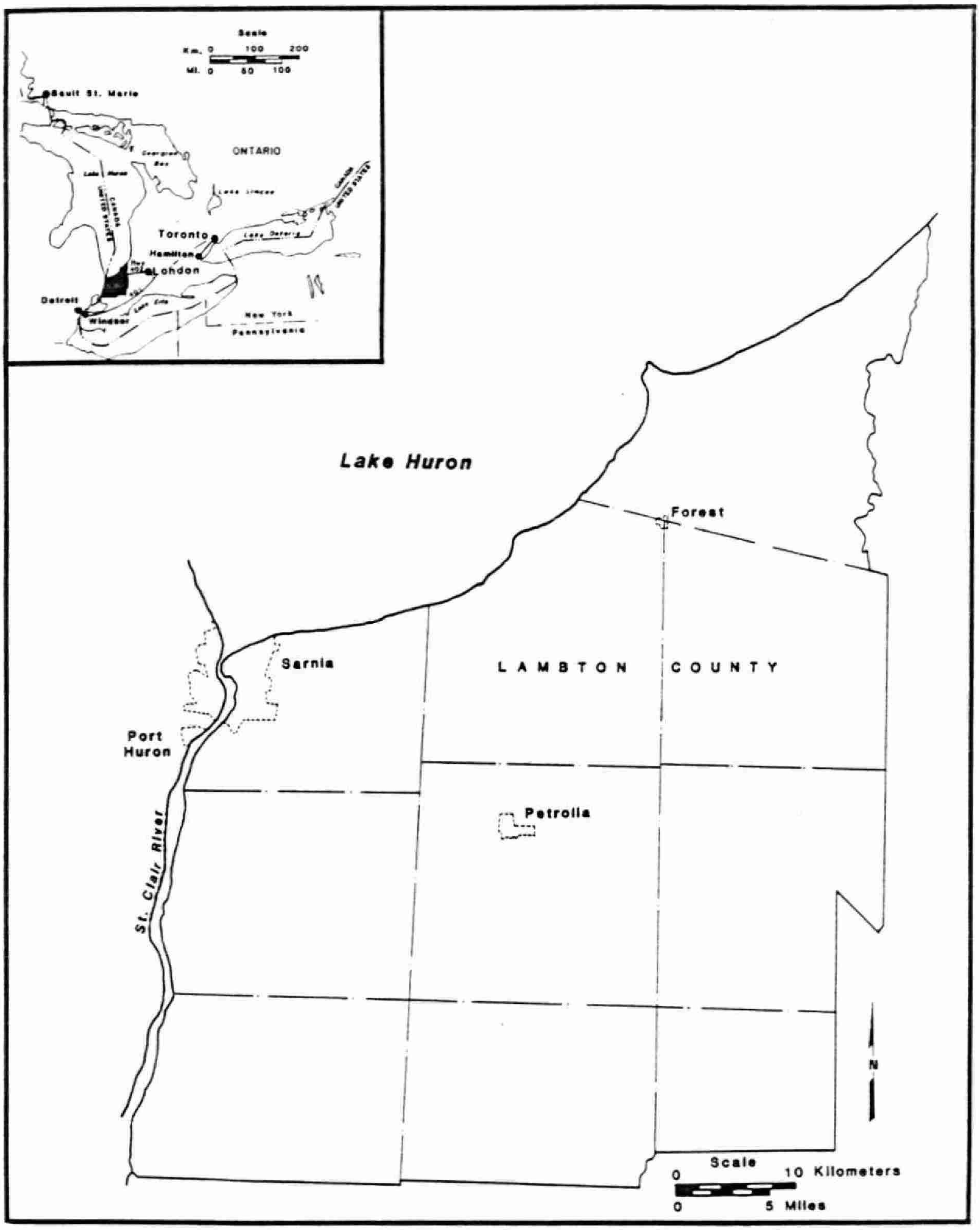

Figure 1. Project Location Map

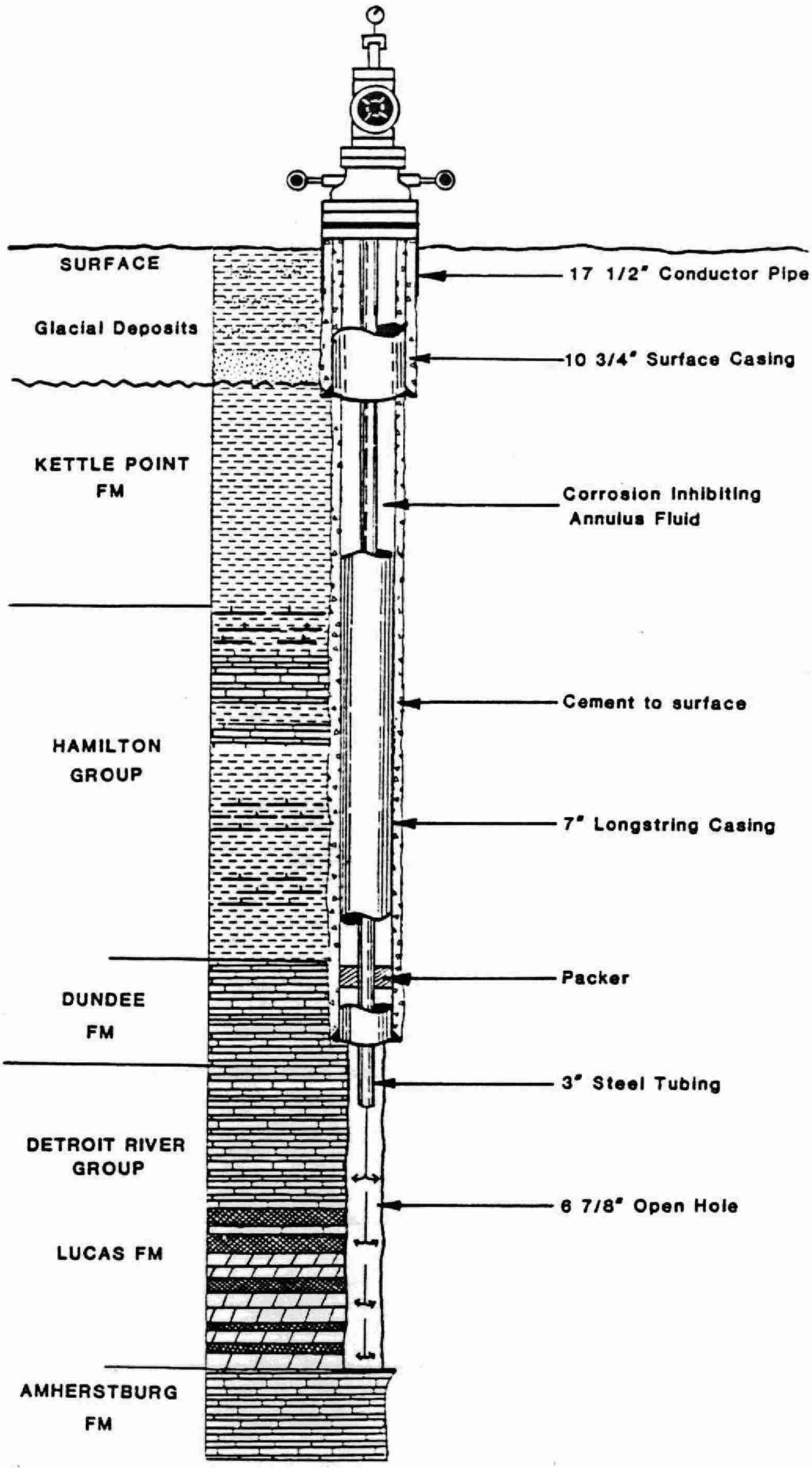

Figure 11. Schematic Diagram of a Typical Brine Injection Well

Company Well Name	Map I.D. No.	Location County	Location TWP	Location Conc.	Location Lot	Well Head Elevation Feet (Meters)	Total Depth Feet (Meters)	Injection Zone Interval Feet (Meters)	Maximum Well-Head Pressure psi (KPa)	Average Injection Rate bbls/day (m^3/day)	Period of Injection	Total Injected bbls (m^3)	Major Type of Waste
Marcus Disposal Well #1	8	Lambton	Enniskillen	5	31	675 (206)	961 (293)	Detroit River Gr. 488'-689' (149-210) 545-580 (166-177)	0 to 150 (1034)	740 (118)	1970-1971	270,000 (42,927)	Spent Caustic Industrial Waste
Thompson Right Company 2 Wells	7A			12	12	670 (204)	852 (260)	550 - 852 (168-260)	50	118 (18.8)	1965-74	490,000 (77,900)	Acid Caustic Brine Oily Water
	7B					673 (205)	1000 (305)		50		1969-74		
Tricil Goodfellow 2 Wells #1	9A	Lambton	Moore	10	9	664 (202)	597 (182)		0	300 (47.7)	1958-1973	1,979,000 (314,636)	Hydrocarbons Chlorides Ethers Phenols
#2	9B			10	9	663.4 (202)	700 (213)	573 - 700 (175-213)	0	?	1973-1976		
Shell Canada Limited #1	3A			Front	68		950 (290)	600 - 900 (183-274)	330 (2275)	1500 (238)	1962-1972	6,260,000 (995,260)	Phenols
#2	3B			Front	68		950 (290)	650 - 950 (198-290)			Not utilized		
Sun Oil Company	4	Lambton	Sarnia	R.R.	19		964 (294)	675 - 964 (206-294)	300 (2068)	1900	1965-1973	3,450,000 (548,506)	Spent Caustic
Polymer Corporation	10			Reg. Plan 12	35		900 (274)		450 (3103)	213 (302)	1961-1970	700,000 (111,291)	Spent Caustic Phenols
Imperial Oil Limited 5 Wells DW1	1A						800 (244)	605 - 800 (184-244)		1200 (191)	1958-1967	47,308,330 (7,521,424)	Spent Caustic Phenols Sulfides
DW2	1B						820 (250)	605 - 820 (184-250)		1200 (191)	1960-1967		
DW3	1C						675 (206)	629 - 675 (192-206)	400-450 (2758-3103)	330 (52.4)	1960-1972		
DW4	1D						820 (250)	635 - 820 (194-250)		2530 (402)	1961-1972		
DW5	1E						820 (250)	635 - 820 (194-250)		2080 (330)	1961-1972		
Canadian Industries Limited 2 Wells #1	5	Lambton	Somora	15	2		1249 (381)	775 - 1234 (236-376)	370 (2551) 100 gpm	1200 (191)	1968-1972	3,750,000 (596,202)	Steam Condensate with ammonia and CO_2
#2	6			15	4	607.5 (185)	1239 (378)	790 - 840 (241-256)	370 (2551)	1200 (191)			
Dow Chemical 2 Wells	2A	Lambton	Sarnia	RR	29			Cavern, Salina Salt 1900'	0		1968-?	4,000 (636)	Waste Oils Solid $CaCO_3$ Residue
	2B				30								

TABLE 1. Industrial Waste Injection Wells, Lambton County, Ontario.

Company Well Name	Map I.D. No.	Location County	TWP	Conc.	Lot	Well Head Elevation Feet (Meters)	Total Depth Feet (Meters)	Injection Zone Interval Feet (Meters)	Maximum Well-Head Pressure psi (KPa)	Average Injection Rate bbls/day (m^3/day)	Period of Injection	Total** Injected bbls (m^3)
Cambrian Disposals Limited #6	15	Lambton	Moore	9	3	650 (198)	800 (244)	Detroit River Group	0	2480 (394.15)	1975-*	7,830,611 (1,243,189)
Cambrian Disposal Limited #11	16	Lambton	Moore	7	3	636 (194)	808 (246)	544-46, 554-56, 609-34 (165-166,169-170) (186-193) Lost Circ. Zone	0		No record.	
Cambrian Disposal Limited #12		Lambton	Moore	9	12				0		No record.	
Cambrian Disposal Limited #1	13	Lambton	Sarnia	1	7	637.8 (194)	928 (283)	575-928 (175-283) 577-587 (176-179) High Perm. Zone	0	10000 (594.33)	1971-*	38,636,749 (6,133,975)
Cambrian Disposal Limited #2	12	Lambton	Sarnia	2	8	625 (190)	900 (274)	551-900 (168-274) perf. 530-544 (162-166)	0	483 (76.8)	1971-1979	2,865,525 (455,582)
Cambrian Disposal Limited #7	11	Lambton	Sarnia	3	4	634.9 (194)	2545 (775)	544-547 (165-166) 572-574 (174-175) Lost Circ. Zone	0	2583 (410.6)	1974-1980	8,717,221 (1,383,947)
Cambrian Disposal Limited #9	14	Lambton	Sarnia	1	4	646 (197)	831 (253)	542-546 (164-165) Lost Circ. Zone	0	440 (70)	1975-1979	1,652,893 (262,789)
Cambrian Disposal Limited #8	21	Lambton	Sombra	6	23	603	1026 (313)	710 (216) Lost Circ. Zone			No record.	

All wells listed are completed in the Detroit River Group.
Locations of wells shown on Plate 1.
* Well is presently active.
**Through December, 1982.

TABLE 2. Cavern Washing Brine Injection Wells, Ontario.

Company Well Name	Map I.D. No.	Location County	TWP	Conc.	Lot	Well Head Elevation Feet (Meters)	Total Depth Feet (Meters)	Injection Zone Interval Feet (Meters)	Maximum Well-Head Pressure psi (KPa)	Average Injection Rate bbls/day (m^3/day)	Period of Injection	Total * Injected bbls (m^3)
Pennzoil #1	25	Lambton	Dawn	1	23	626 (191)	1,000 (305)		350 (2413)	5.8 (0.92)	1965-1976	67,960 (10,805)
Central Pipeline Company	24	Lambton	Dawn	1	20				300 (2068)	20 (3.18)	1972	3,400 (540.6)
Colonial Petroleum #21	26	Lambton	Dawn	2	23	626.1 (191)	734 (224)		450 (3103)	50.9 (8.1)	1962-1981	399,400 (63,508)
Higgs Disposal	27	Lambton	Dawn	9	28	663 (202)	705 (228)				1981	
Consumers Gas Well 6177	18	Lambton	Dawn	5	10	625 (190)	2178 (664)		0	1 (0.16)	1965-1981	4,020 (639) Brine - D. Riv. still active. Personal Communications.
Esso Imperial Corruna #3	17	Lambton	Dawn	10	19	597 (182)	700 (213)		0	22.9 (3.64)	1960-1981	176,683 (28,190.4)
Murphy Oil Company (I.O.L.)	20	Lambton	Dawn	5	9	581 (177)	1000 (305)		0	93.7 (14.9)	1980-1981 Still Active	50,809 (8,078)
Cameron Petroleum	19	Lambton	Dawn	10	6				0		1970 only record	2,018 (320.8)
Anchor 4 Wells	22	Lambton	Sombra	30	11						1965-1968	218,400 (34,723)
Rayrock, J. Bradden #31	29	Elgin	Aldborough	5	4	694 (211)	648 (198)	450 - 648 (137-198)	500 (3448)	3340 (531)	1964-1981	19,043,697 (3,027,706
Rayrock	30	Elgin	Aldborough	5	4	698 (213)	640 (195)				1982	
Canada Cities Service Rodney Unit Tr. 5	31	Elgin	Aldborough	5	5	660 (201)	716 (218)		362 (2500)	3133 (498)	1962-1981	15,869,941 (2,523,119
Rayrock Downie 102	28	Elgin	Aldborough	Gore	2	693 (211)	1722 (525)		400 (2758)	1635 (260)	1964-1981	6,757,452 (1,705,739
I.U. Petroleum Corp/ Imp. Bluewater	32	Elgin	Dunwich	2	23	720 (219)	3652 (1113)		450 (3103)	230 (36.6)	1965-1981	2,393,745 (380,575
Putnam Canadian, Devonian 3	38	Essex	Gosfields	WDFC	4	623 (190)	1070 (396)				1981	New well no record of injection
Kerodec #2	23	Kent	Chatham	9	22				0		1974-1976	517.6 (82.3)

Locations of wells shown on Plate 1.
*Through December, 1981.

TABLE 3. Oilfield Brine Injection Wells, Detroit River Group.

ERA	SYSTEM	GROUP	FORMATION	PRIMARY LITHOLOGY	APPROX. DEPTH in LAMBTON CO. Ft. (m)
Cenozoic	Pleistocene		Glacial Till	Sand, Clay	0
Paleozoic	Devonian	Port Lambton		Shale	Missing at Well site
			Kettle Point	Shale	170 (52)
		Hamilton	Ipperwash	Limestone	320 (98)
			Widder	Shale and Limestone	
			Hungry Hollow	Limestone and Shale	
			Arkona	Shale	
			Rockport Quarry	Limestone	
			Bell	Shale	
			Marcellus	Shale w/Limestone	
			Dundee ● ☼	Limestone	580 (177)
		Detroit River	Lucas ●	Dolomite	715 (218)
			Amherstburg	Limestone and Dolomite	950 (290)
			Bois Blanc	Dolomite and Limestone	1115 (340)
			Oriskany	Sandstone	
	Silurian		Bass Islands	Dolomite	1180 (360)
			Salina ● ☼	Halite, Anhydrite, Limestone, Dolomite, Shale	1330 (405)
			Guelph-Lockport ● ☼	Dolomite	2510 (765)
		Amabel	Queenston ☼	Dolomite	2540 (774)
		Cataract	Grimsby ● ☼	Sandstone	2625 (800)
			Cabot Head	Shale	
			Manitoulin	Dolomite	
			Whirlpool ● ☼	Sandstone	
	Ordovician			Shale	2820 (860)
			Meaford-Dundas	Shale	
			Blue Mountain	Shale	
			Collingwood	Shale	
		Trenton	Cobourg ☼	Limestone	3440 (1049)
			Sherman Fall ● ☼	Limestone and Shale	
			Kirkfield	Limestone	
		Black River	Coboconk ☼	Limestone	3925 (1196)
			Gull River ☼	Limestone	
			Shadow Lake	Shale	
	Cambrian		Trempealeau	Dolomite	4450 (1356)
			Eau Claire ● ☼	Dolomite and Sandstone	
			Mount Simon	Sandstone	
Precambrian				Igneous Rocks	4520 (1378)

Depths from electric log of Imperial Moore No. 49 R.F., Moore Township

Adapted from Geol. Surv. Canada, 1969, McLean, 1968, and Booth-Horst and Rybansky, 1982

● Oil ☼ Gas

TABLE 5. Stratigraphic Succession in Southwestern Ontario

Map I.D. No.	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
DETROIT RIVER GROUP												
13	616,532 (3,878,280)	1,051,872 (6,616,776)	1,028,566 (6,470,170)	791,779 (4,980,667)	717,525 (4,513,574)	312,356 (1,964,868)	194,040 (1,220,604)	186,965 (1,176,099)	216,932 (1,364,606)	262,596 (1,654,043)	344,902 (2,172,472)	204,950 (1,290,941)
12	4,371 (27,496)	126,907 (798,305)	62,634 (393,998)	28,086 (176,674)	60,659 (381,574)	33,237 (209,077)	41,148 (258,840)	41,148 (258,840)	28,036 (176,360)			
15					38,367 (241,347)	408,022 (2,566,653)	134,256 (884,534)	123,051 (774,049)	143,864 (904,973)	147,335 (928,036)	79,801 (502,651)	24,020 (151,297)
11				109,578 (689,298)	392,094 (2,466,458)	245,180 (1,542,299)	224,661 (1,413,225)	224,661 (1,413,225)	149,876 (942,791)	6,034 (38,011)		
14					20,164 (126,841)	111,133 (70,032)	41,894 (263,533)	22,122 (139,158)	25,582 (160,923)			
TOTAL	620,903 (3,905,776)	1,178,779 (7,415,081)	1,091,200 (6,864,168)	929,443 (5,846,639)	1,228,809 (7,729,794)	1,109,928 (6,352,929)	635,999 (4,040,736)	597,947 (3,761,371)	564,290 (3,549,653)	415,965 (2,620,090)	424,703 (2,675,123)	228,970 (1,442,238)

Totals injected by year m^3 (BBLS).
Locations of wells shown on Plate 1.
Descriptions of wells in Table 2.

TABLE 7. Annual Volumes of Cavern-Washing Brine Injected into the Subsurface 1971-1982.

Figures in m^3 (BBLS)

Map I.D. No.	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
DETROIT RIVER GROUP												
25	995 (6,259)	1,441 (9,315)	506 (3,183)	450 (2,831)	414 (2,604)	105 (661)	105 (661)					
24			540 (3,397)									
26	2,191 (13,782)	2,270 (14,279)	1,962 (12,342)	2,196 (13,814)	2,580 (16,229)	3,106 (19,536)	2,103 (13,229)	3,210 (20,192)	3,520 (22,142)	3,580 (22,520)	3,190 (20,067)	2,420 (15,223)
27												
18	61 (377)	33 (207)	61 (384)	36 (226)	21 (132)	15 (94)	63 (396)	37.8 (238)		43 (271)	81 (509)	87.08 (547)
17	543 (3,415)	293 (1,843)	527 (3,315)	337 (2,120)	216 (1,359)	271 (1,705)	271 (1,705)	395 (2,485)	540 (3,397)	565 (3,555)	597 (3,755)	742 (4,668)
20											2,640	5,428
19	321 (2,019)											
29	197,300 (1,241,111)	196,820 (1,238,092)	220,500 (1,380,050)	223,730 (1,407,368)	230,500 (1,449,355)	223,400 (1,405,272)	206,980 (1,302,003)	208,160 (1,309,344)	208,663 (1,312,647)	205,123 (1,290,321)	200,620 (1,261,995)	193,940 (1,220,230)
30												
31	157,000 (987,605)	163,865 (1,030,789)	173,640 (1,092,278)	154,086 (969,274)	188,165 (1,183,648)	215,250 (1,354,025)	171,010 (1,075,743)	174,090 (1,095,134)	184,300* (1,159,334)	184,300* (1,159,334)	194,580 (1,224,000)	181,800 (1,143,609)
28	52,225 (328,520)	58,030 (365,036)	69,630 (438,006)	70,750 (445,051)	63,555 (399,791)	78,370 (492,994)	82,380 (518,209)	81,860 (514,938)	83,730 (526,762)	92,640 (582,750)	91,355 (574,666)	94,822 (596,476)
32	1,865 (11,732)	1,270 (7,989)	1,840 (11,574)	1,940 (12,204)	5,870 (36,925)	8,600 (54,098)	10,390 (65,358)		13,350 (83,978)	13,490 (84,857)	14,705 (95,501)	
38												
23					33 (208)	49 (308)			494,120 (3,107,921)			
22												
Subtotal Detroit Riv. Gp.	412,501 (2,594,829)	424,062 (2,667,552)	469,206 (2,951,529)	453,525 (2,652,868)	491,354 (3,090,851)	529,166 (3,324,736)	473,302 (2,977,295)	467,693 (2,942,012)	494,120 (3,107,921)	499,741 (3,143,276)	507,768 (3,194,103)	479,289 (3,014,956)
GUELPH FORMATION												
35							690 (4,340)	715 (4,498)				
37		1,590 (10,002)	1,780 (11,197)	1,217 (7,656)	1,450 (9,121)	1,415 (8,901)	1,616 (10,165)	1,663 (10,460)				
20				2,321 (14,600)			690 (4,340)	713 (4,485)	1,093 (6,875)	1,160 (7,297)	2,437 (15,330)	2,611 (16,424)
34	8,890 (55,922)	5,570 (35,038)	7,700 (48,436)	7,120 (44,788)	8,280 (52,085)	6,565 (41,294)	4,040 (25,414)	4,810 (30,257)	8,380 (52,714)	7,630 (47,996)	5,621 (35,359)	2,630 (16,544)
33	2,540 (15,978)	2,330 (14,657)	2,203 (13,858)	1,972 (12,405)	1,915 (12,046)	2,000 (12,581)	**	**	3,150 (19,815)	9,940 (62,527)	14,500 (91,212)	15,510 (97,565)
								6,922 (43,543)	21,490 (135,181)	20,740 (130,464)	16,822 (105,818)	19,164 (120,550)
Subtotal Guelph		9,490 (59,692)	11,683 (73,486)	12,630 (79,449)	11,645 (73,244)	9,980 (62,772)	7,036 (44,255)	14,823 (93,234)	34,113 (214,564)	39,470 (248,259)	39,380 (247,693)	39,915 (251,058)
Annual Total Injected	423,931 (2,666,728)	433,552 (2,727,218)	480,889 (3,025,021)	466,155 (2,932,337)	502,999 (3,164,103)	539,146 (3,391,435)	480,338 (3,021,555)	482,516 (3,035,255)	528,230*** (3,322,816)	539,211*** (3,391,894)	547,148 (3,441,822)	519,024 (3,266,908)
Total Oil Production	166,692 (1,048,176)	152,326 (958,203)	139,608 (878,201)	128,565 (808,735)	116,707 (734,142)	111,976.4 (704,395)	99,812 (627,865)	98,372 (618,807)	95,144 (598,501)	91,904 (574,623)	93,881 (590,556)	
Total Gas Production	471,646 (2,966,878)	458,000 (2,881,038)	350,561 (2,205,204)	269,912 (1,697,575)	213,507 (1,343,061)	309,750 (1,948,664)	140,440 (883,434)	241,524 (1,519,301)	352,999 (2,220,537)	367,931 (2,340,271)	445,232 (2,800,720)	

* No data for this year; volume was estimated by averaging values for 1971 and 1980.
** No record; volume not estimated.
***Value includes estimated volumes for Well I.D. No. 31.

TABLE 8. Annual Volumes of Oilfield Brine Injected into the Subsurface 1970–1981.

(12013)
MOE/ENV/AOMB

	DATE DUE		

MOE/ENV/AOMB
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